The SuperKEKB Project

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on behalf of the KEKB accelerator team

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PANIC05
Particles and Nuclei International Conference
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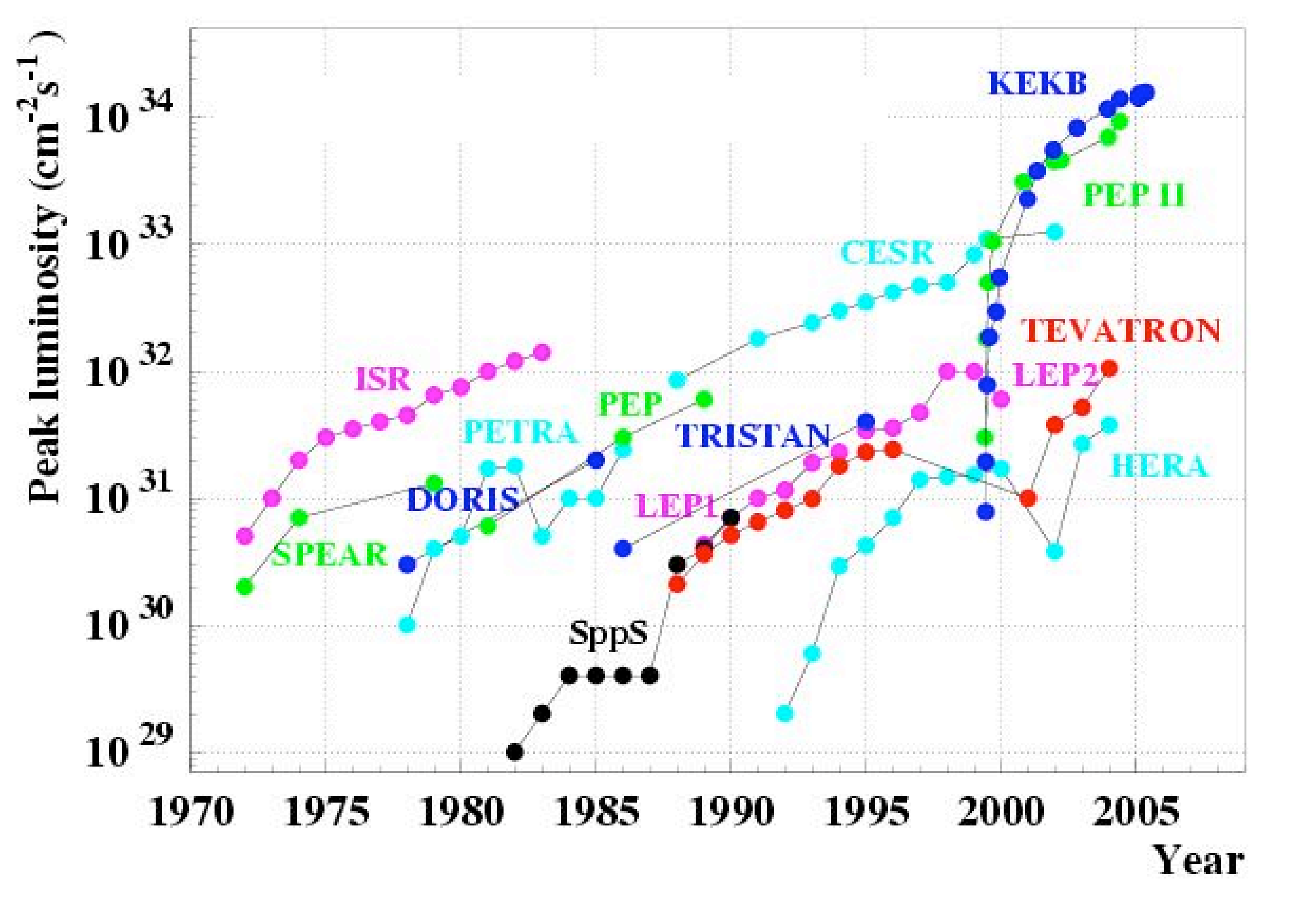
What is SuperKEKB ?

- An asymmetric-energy* double-ring e^+e^- collider proposed to advance the luminosity frontier of HEP beyond 10^{35} cm^{-2} s^{-1}.
- To be constructed by upgrading the KEKB collider, currently providing the highest luminosity (1.58 x 10^{34} cm^{-2} s^{-1}) on the planet.

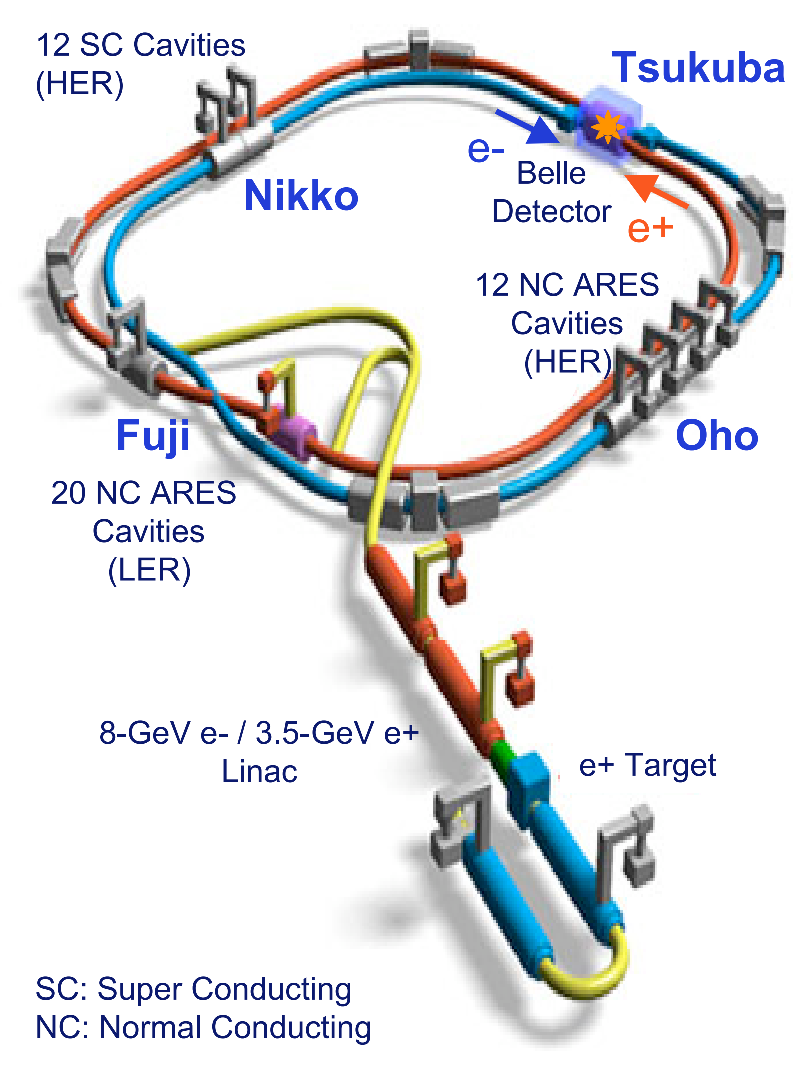
* 3.5-GeV x 8.0-GeV

Peak Luminosity Trends



KEKB
Asymmetric-Energy Double-Ring Collider for B-Physics

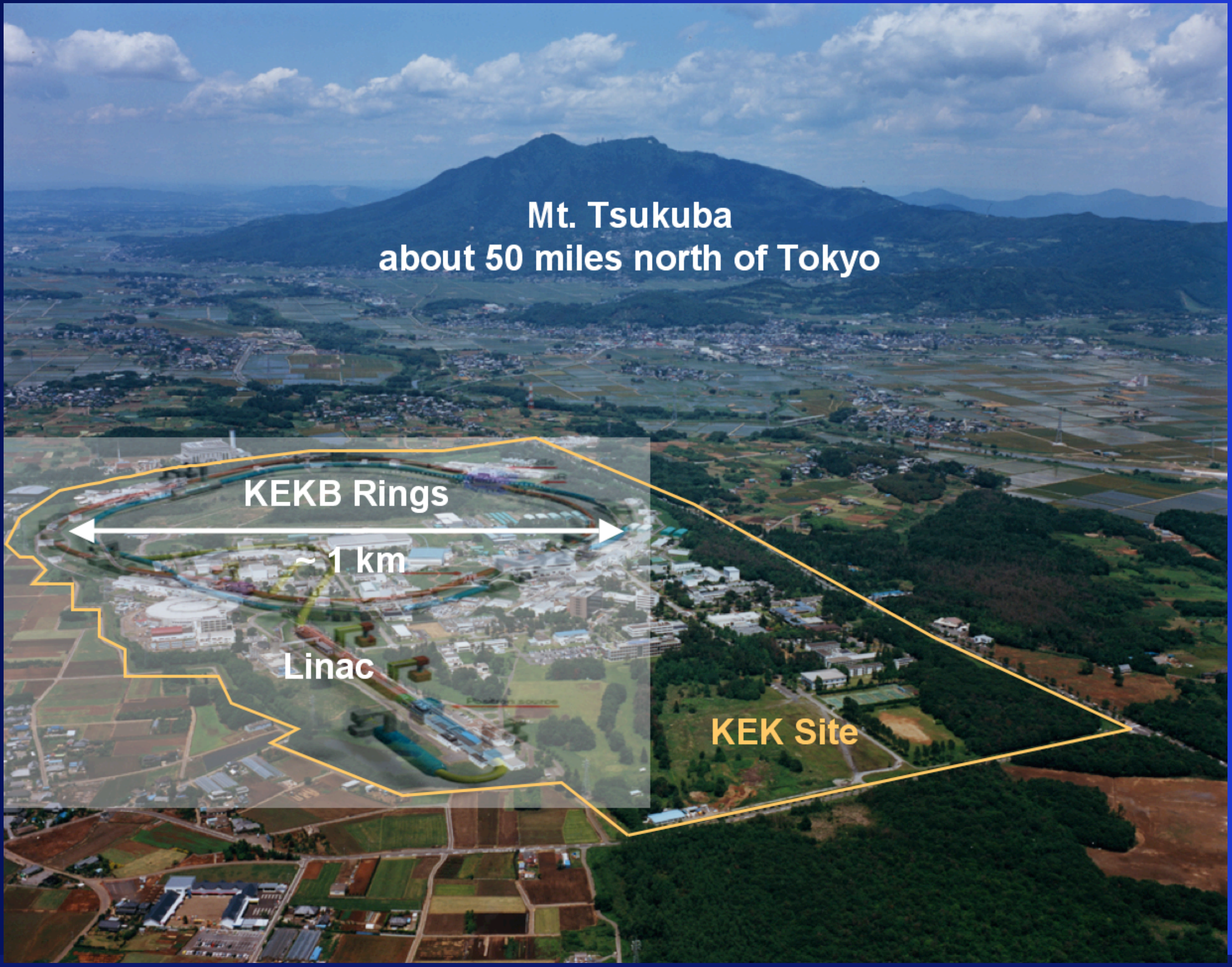
8-GeV e⁻ beam (HER) x 3.5-GeV e⁺ beam (LER)



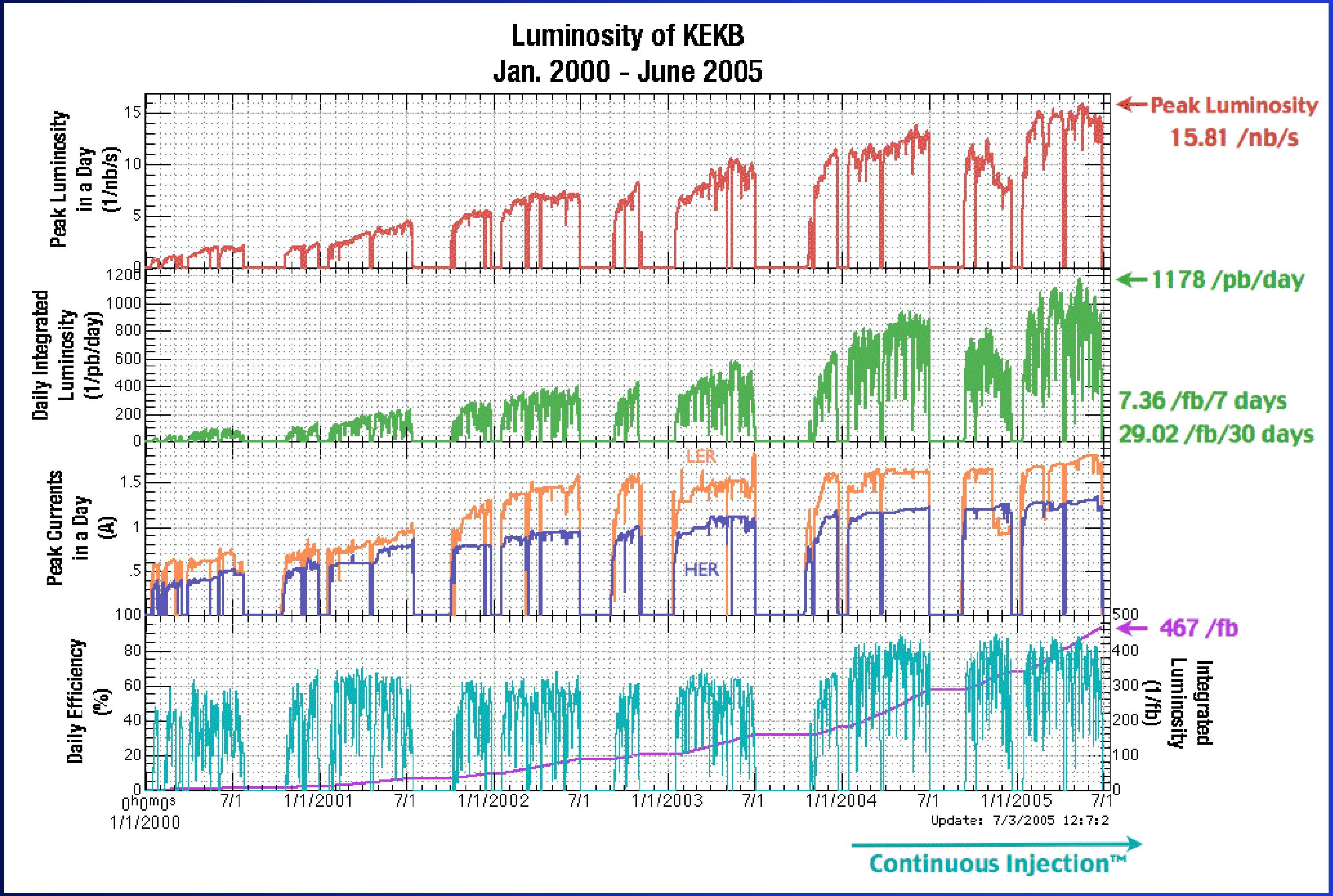
1989:	**Design work started.**
1994:	**Approval of the budget, construction started.**
Jun. 1995:	**KEKB Design Report**
Sep. 1997:	**Commissioning of the injector Linac started.**
Dec. 1998:	**First beam at HER.**
Jan. 1999:	**First beam at LER.**
May 1999:	**Belle roll-in.**
Jun. 1999:	**First event at Belle.**
Apr. 2001:	**World record of the luminosity, 3.4×10^{33} cm^{-2} s^{-1}.**
Oct. 2002:	**World record of the integrated luminosity, 100 fb^{-1}.**
May 2003:	**Exceeded the design luminosity, 1.0×10^{34} cm^{-2} s^{-1}.**
Mar. 2005:	**1.5×10^{34} cm^{-2} s^{-1} and integrated luminosity per day > 1000 pb^{-1}**
Oct. 2005:	**Integrated luminosity > 480 fb^{-1}**

Where is KEKB?

The KEKB double-ring collider is located near Mt. Tsukuba with twin peaks.

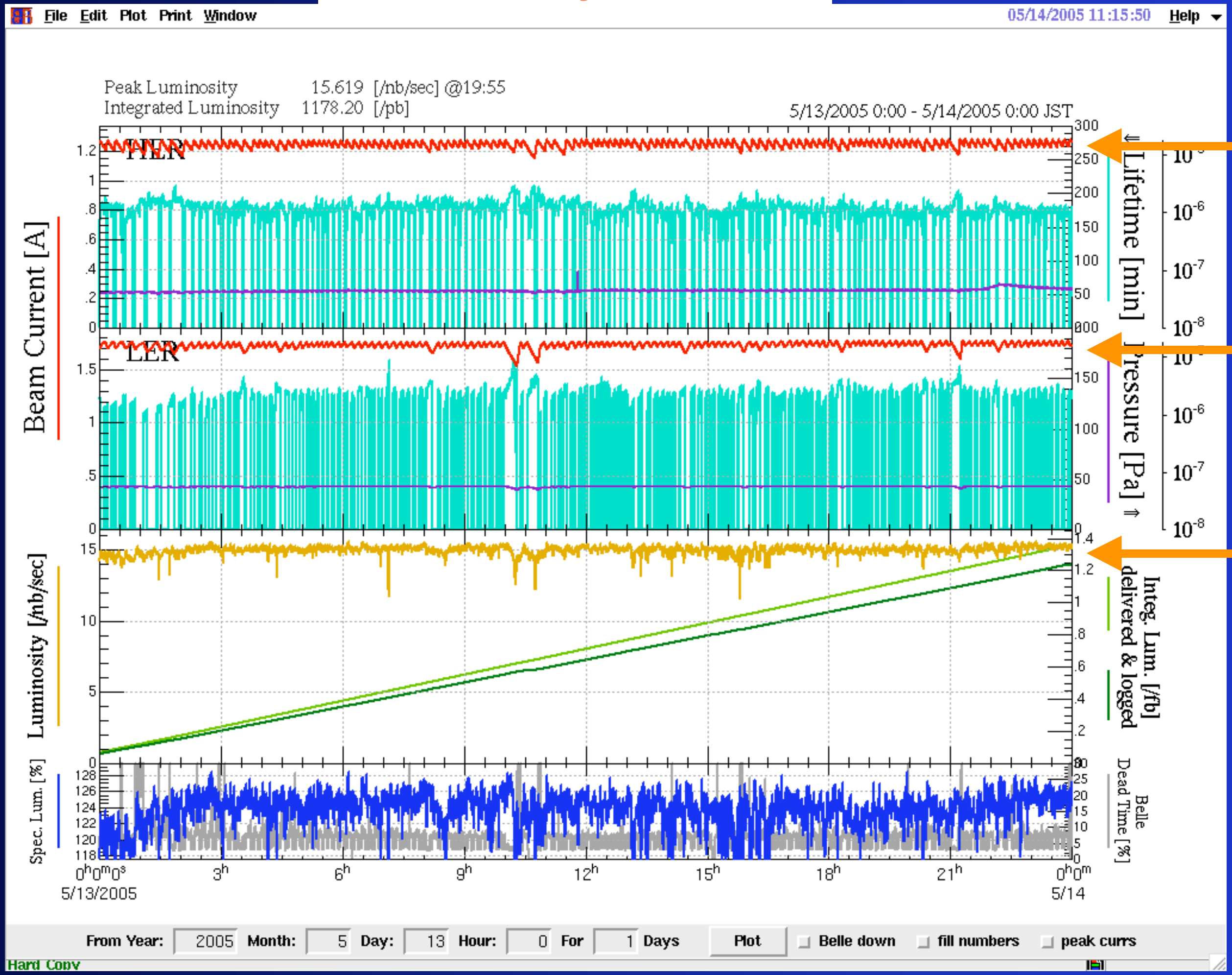


KEKB Machine Performance Steadily Improving …



Stable and Smooth Operation

The Best Day: 5/13/2005



I_{HER} = 1.25 A

I_{LER} = 1.73 A

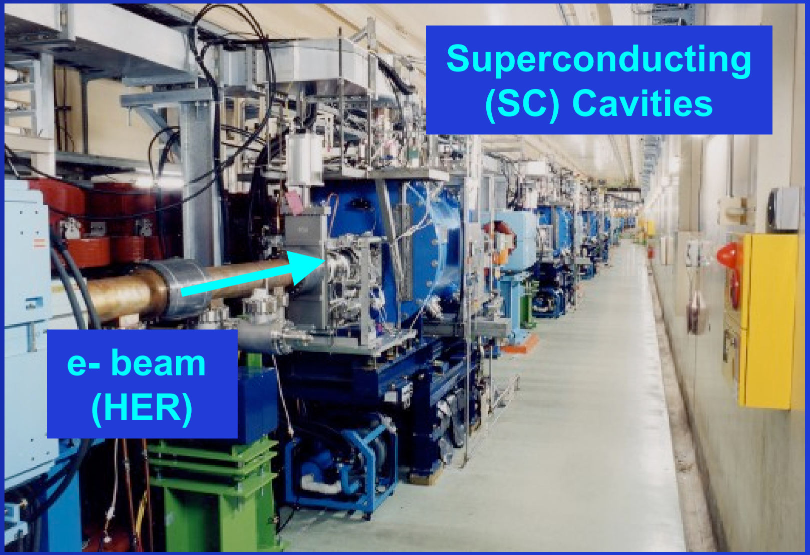
$L = 1.5 \times 10^{34}$ cm^{-2} s^{-1}

1178 pb^{-1} per day

Stable Acceleration of High Current Beams

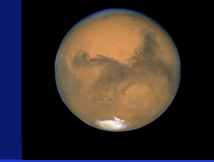
- HER beam up to 1.34 A by 12 NC ARES Cavities and 8 SC Cavities.
- LER beam up to 1.86 A by 20 NC ARES Cavities.

Fuji RF Section



Nikko RF section

What is ARES Cavity ?



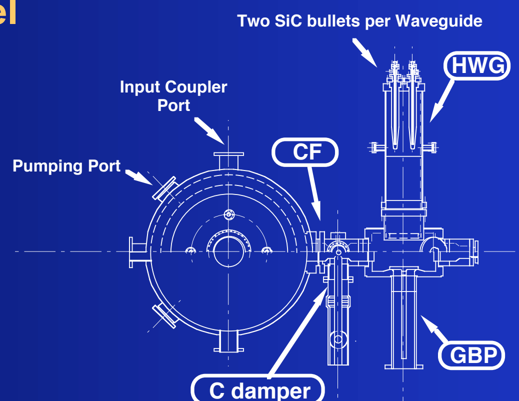
Accelerator Resonantly coupled with Energy Storage

3-cavity system stabilized with the $\pi/2$-mode operation

- S cavity functions as an EM flywheel to stabilize the accelerating mode against heavy beam loading:

$$U_s/U_a = 9$$

U_s : EM stored energy in S cavity
U_a: EM stored energy in A cavity

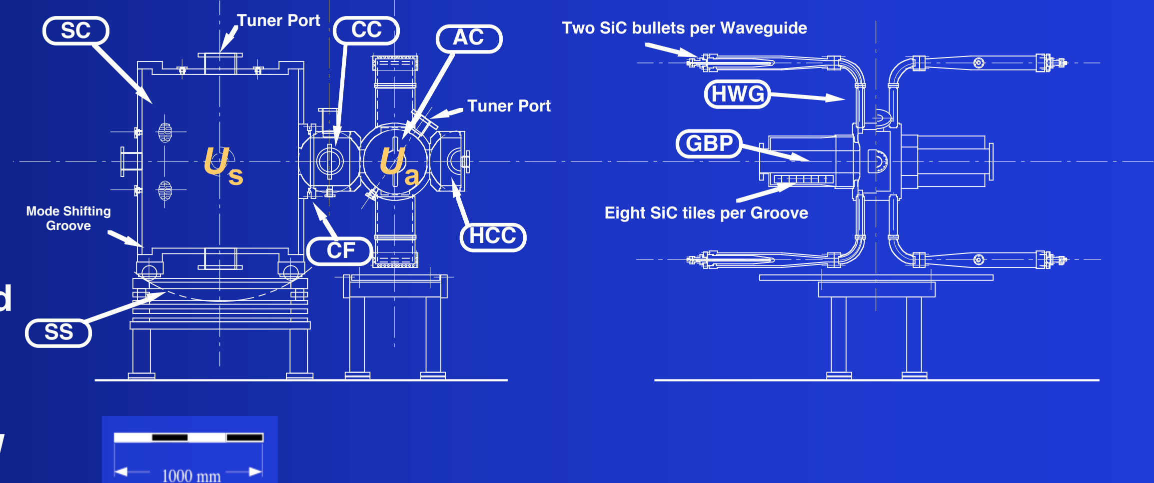


AC: Accelerating Cavity (HOM-damped)

SC: Storage Cavity (TE013)

CC: Coupling Cavity damped with an antenna-type coupler (C damper)

- No need for longitudinal bunch-by-bunch feedback.
- The accelerating cavity is equipped with RF absorbers (SiC) to damp Higher Order Modes (HOMs) induced by the bunched beam.
- Input coupler operated up to 460 kW (up to 800 kW at test stand).



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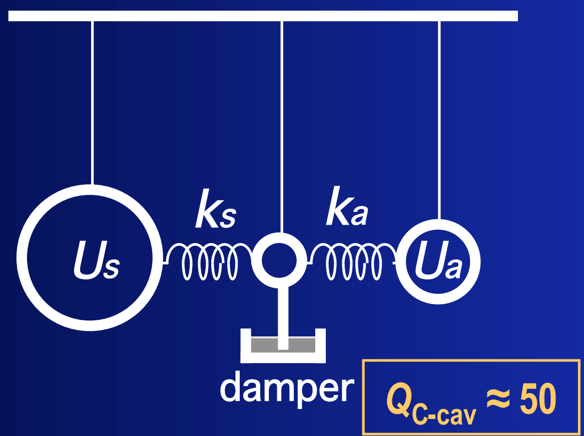
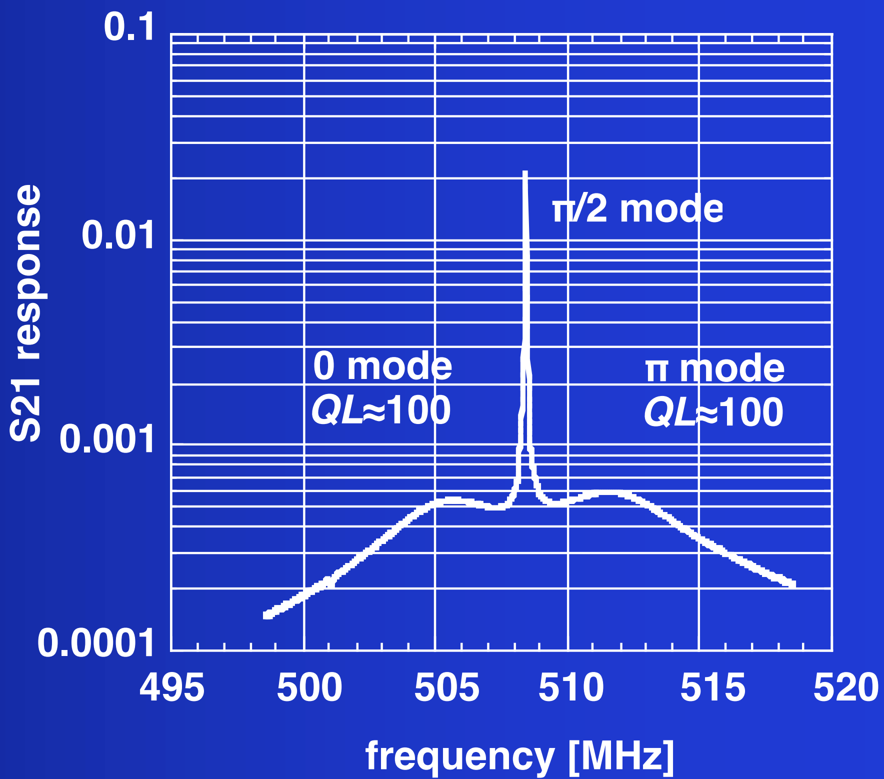
Fundamentals of the ARES Cavity System



mode	S-cav	C-cav	A-cav
0	→	→	→
π/2	→	•	←
π	→	←	→



$$\frac{U_s}{U_a} = \frac{k_a^2}{k_s^2}$$ for $\pi/2$ mode

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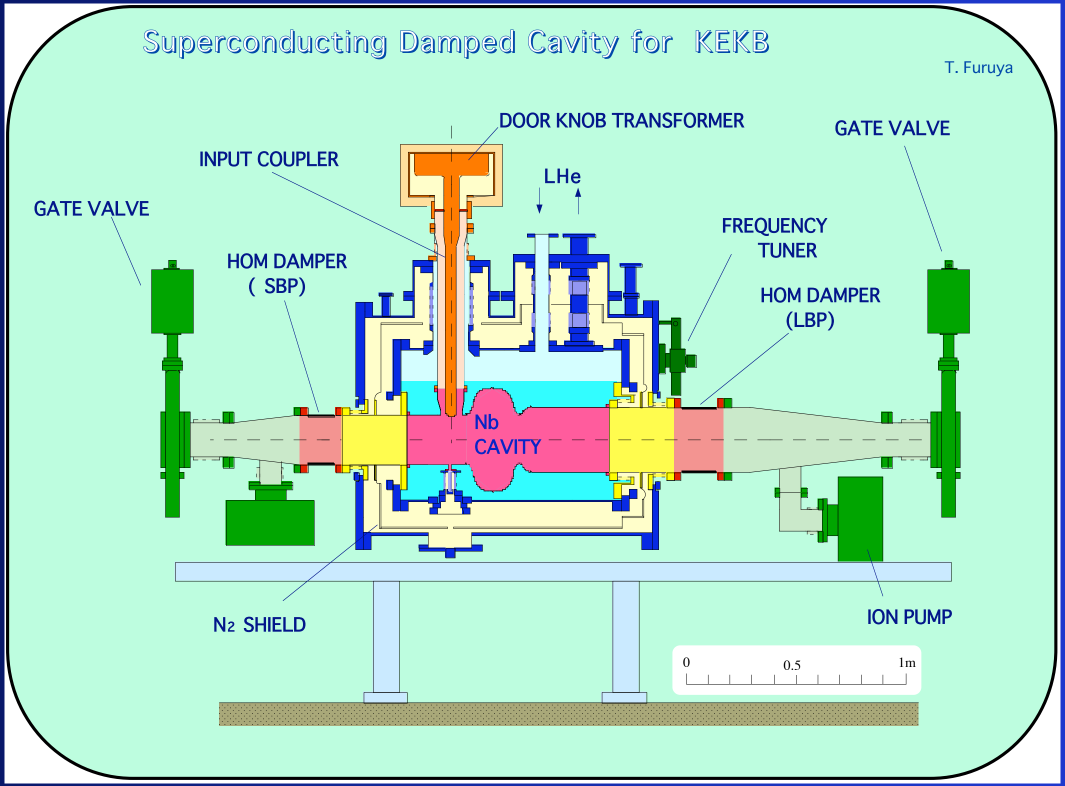
KEKB Superconducting Cavity

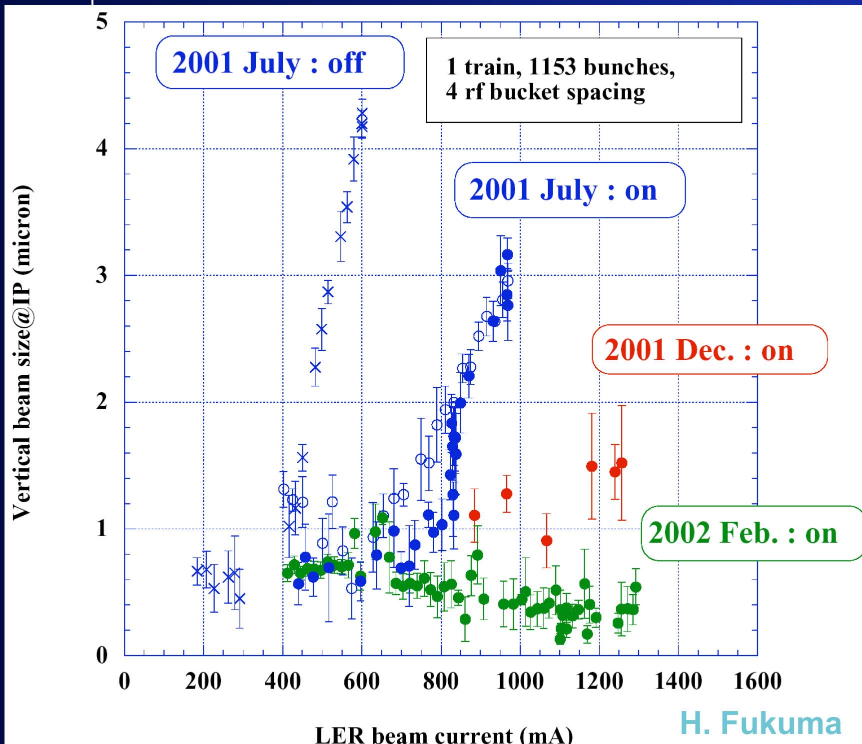


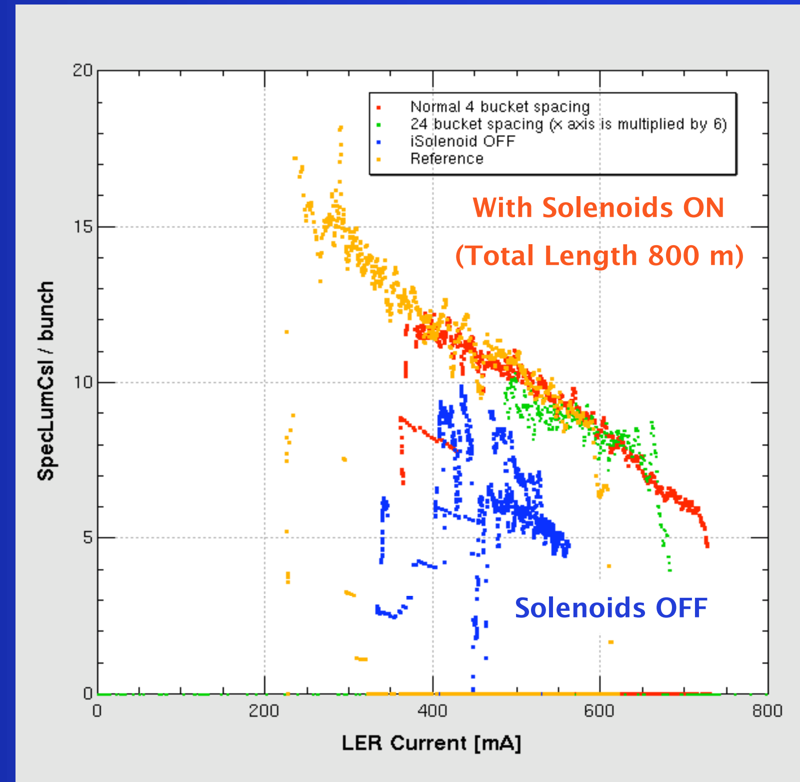
- HOM-damped SC cavity of cylindrical symmetry, equipped with HOM absorbers (ferrite).

- KEKB SC cavity accelerating the highest current of 1.34 A on the planet.

- Input coupler operated up to 380 kW.

Electron Clouds Cleared Up !
But not as clear as the sky over Santa Fe.



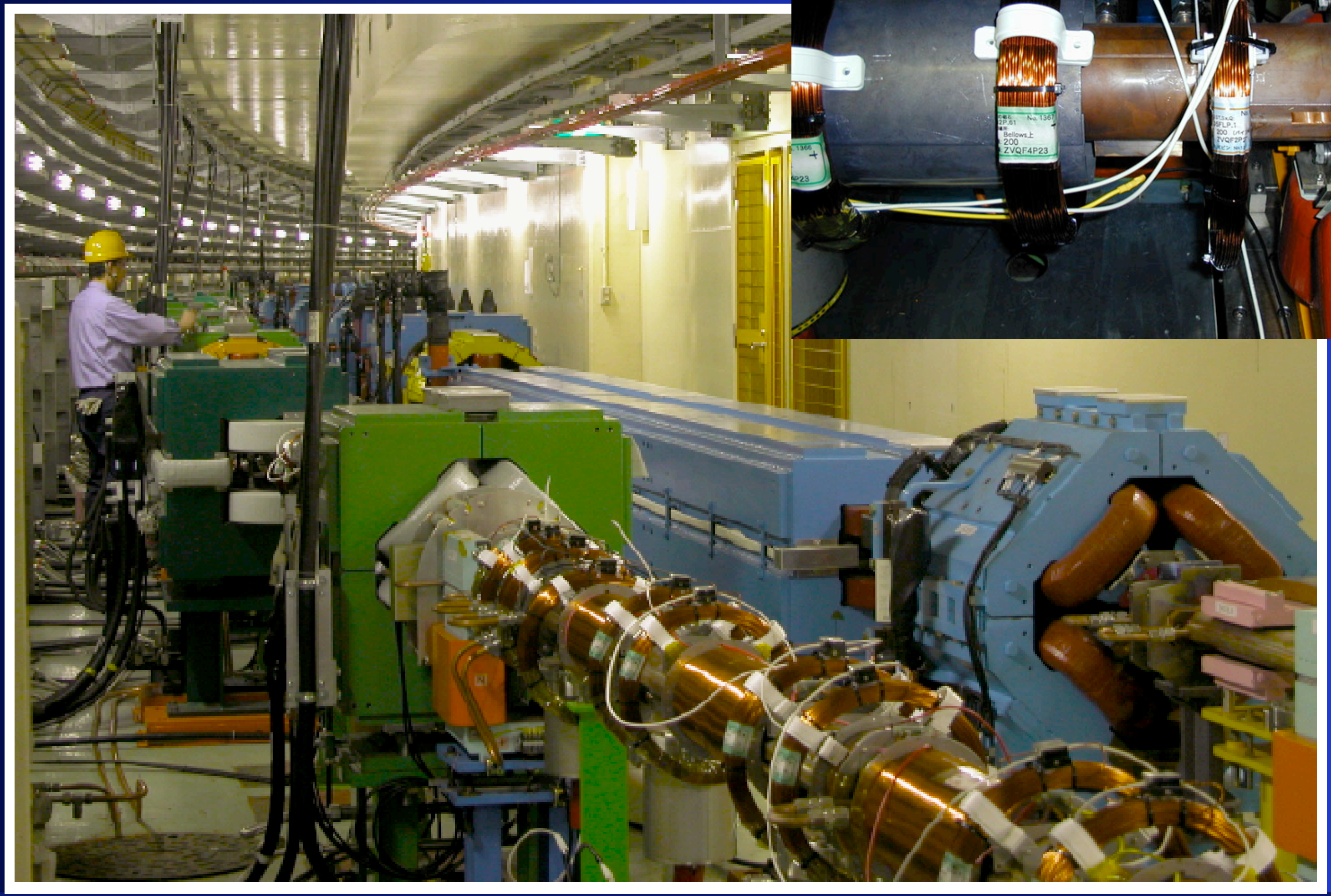


- Blow-up of the vertical beam size in LER (e+) has been suppressed by winding solenoids around the LER beam ducts.

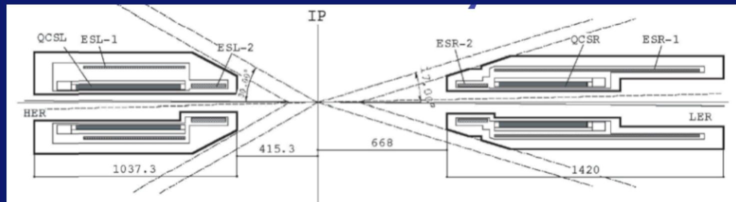
- The total length covered by solenoids reached 2300 m, about 95% of the drift space.

Specific luminosity vs. LER current: Solenoids are just so effective.

Solenoid Winding Continues to Reduce the Cloud Cover.



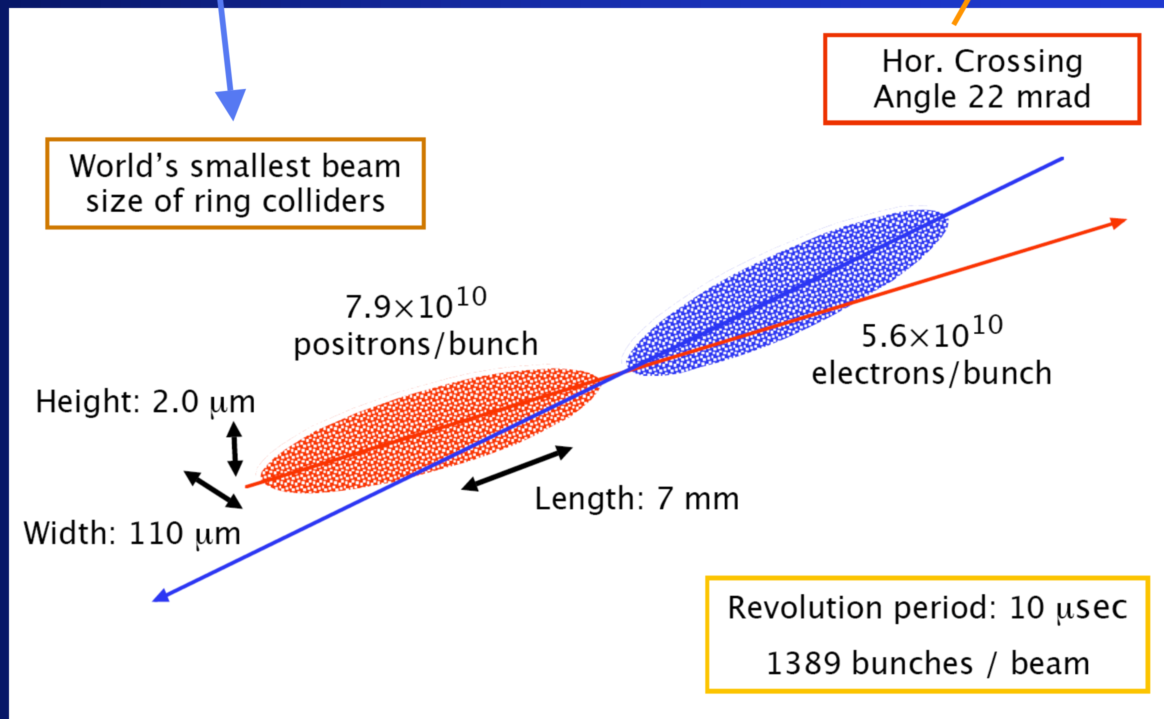
Beam-Beam Collision Scheme in KEKB



Superconducting Quadrupole Magnets for Final Focus

Merits

- Large beam separation near the IP
- Room for optimization of IR lattice
- Reduction of beam background



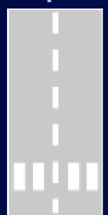
KEKB's beam-beam collision scheme with a finite crossing angle has been working well as expected.

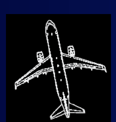
Crabbing Maneuver

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

You're cleared to land.

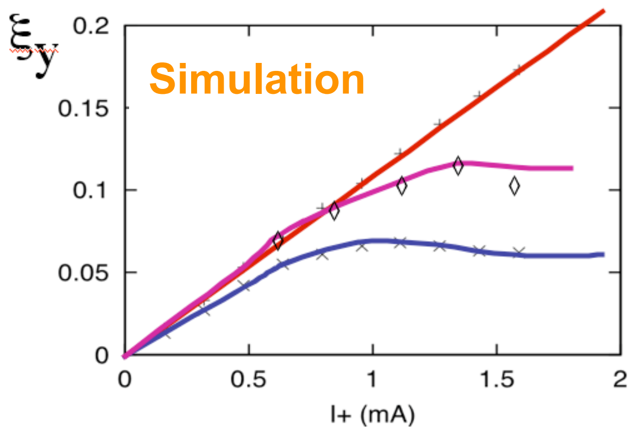
ABQ Sunport

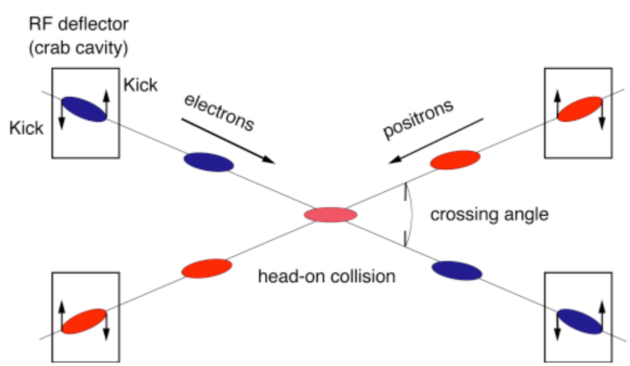




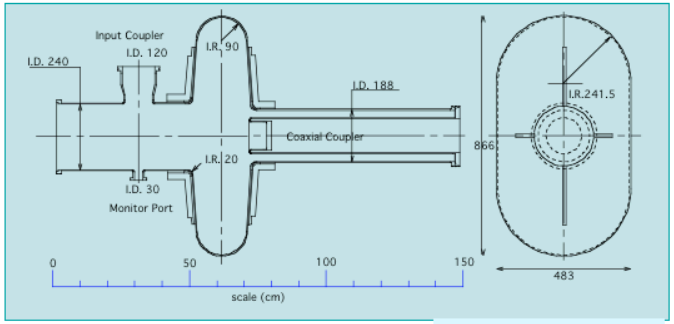
Crosswind Landing by Crabbed Approach

- Crab crossing will boost the beam-beam parameter up to 0.14!





- Superconducting crab cavities are under development, will be installed in KEKB in early 2006.



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According to simulation studies, a head-on colliding of crabbed bunches can further boost the KEKB performance.

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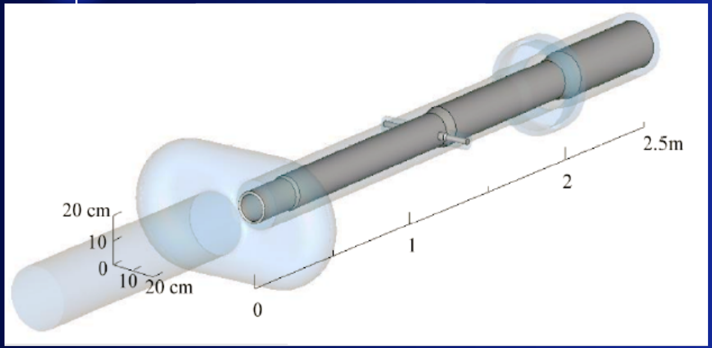
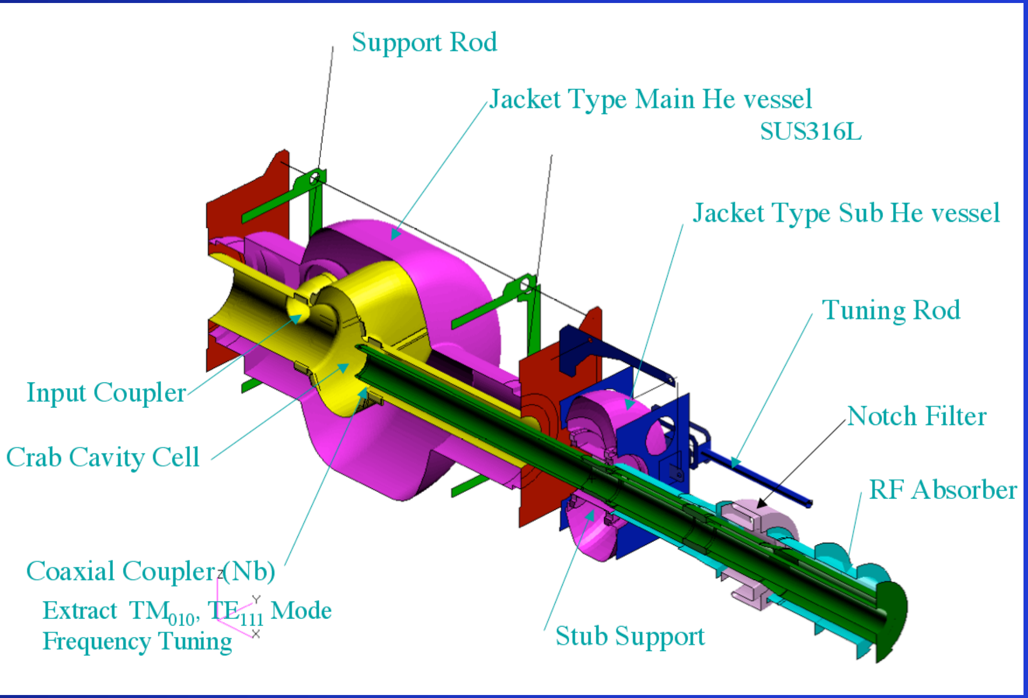
Superconducting Crab Cavity for KEKB



Crab cavity loaded with coaxial coupler for damping HOMs & LOMs other than the deflecting dipole mode.



Crab cavity in He vessel

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Crab Cavity Cell under Surface Treatment by High-Pressure Water Rinse

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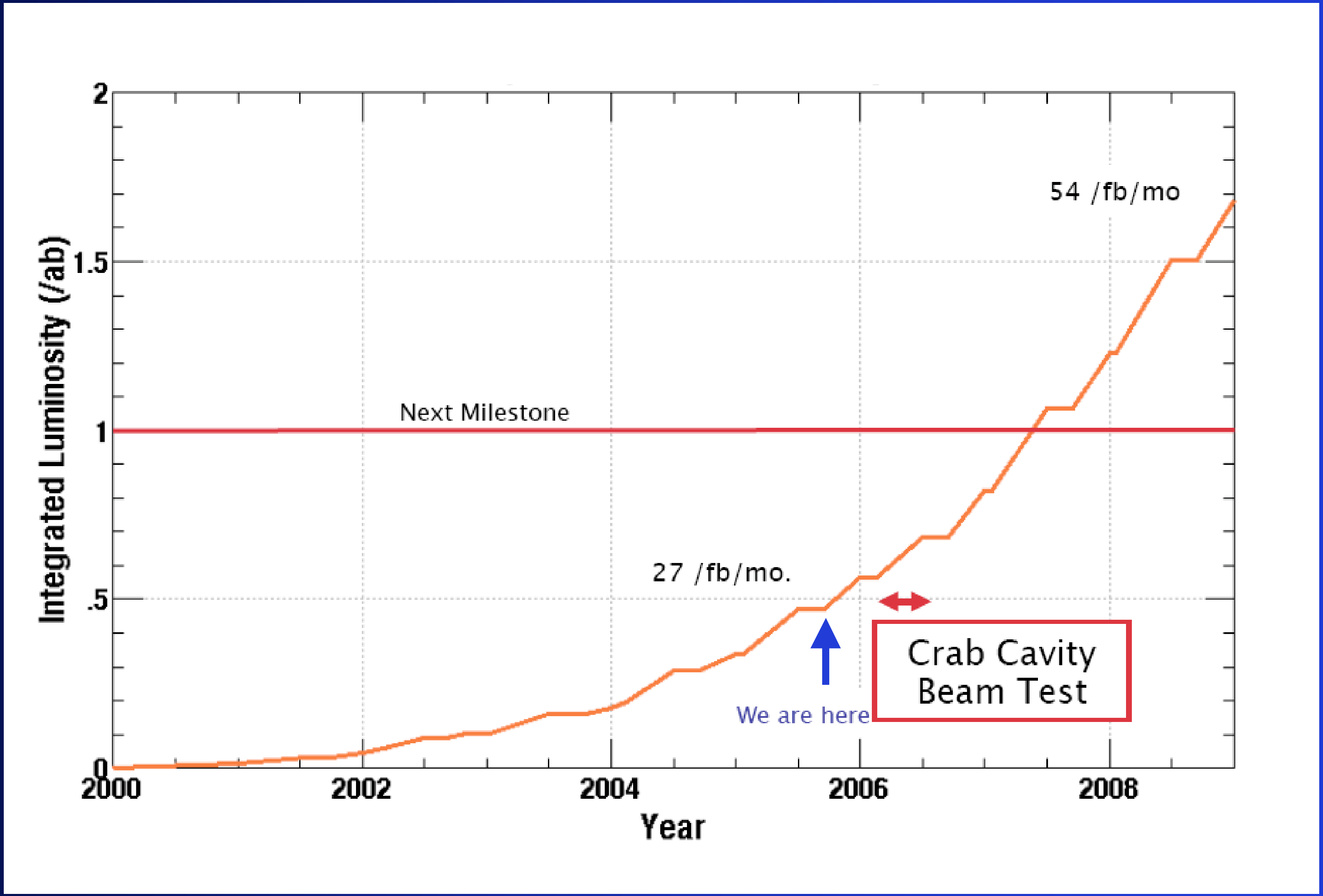
Projection of KEKB Luminosity



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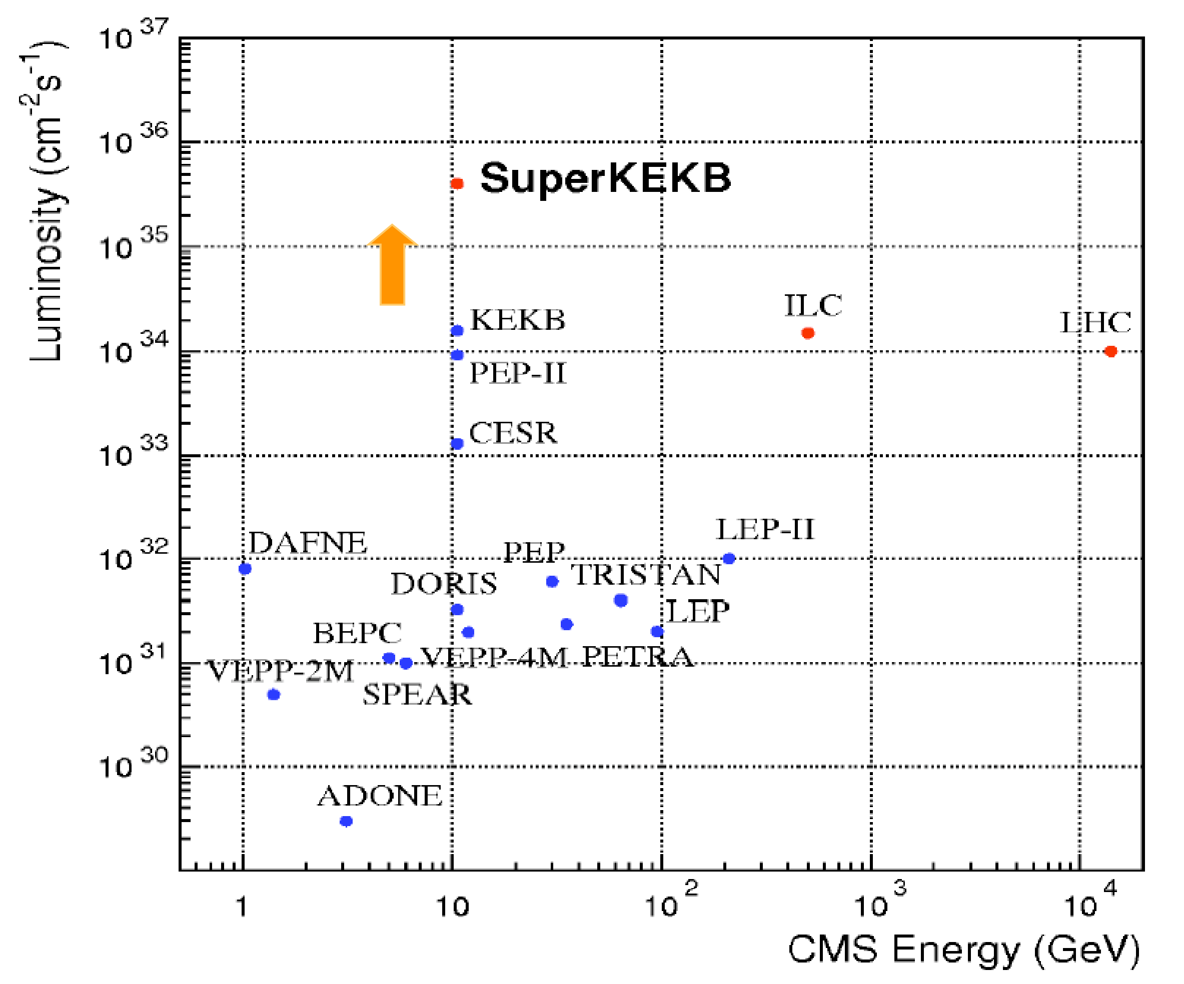
SuperKEKB

Next Step to Advance the Luminosity Frontier beyond 10^{35} cm^{-2} s^{-1}.



Advancing the luminosity frontier, orthogonal to the energy frontier, is also indispensable for deepening our understanding of the universe.

Upgrading from KEKB to SuperKEKB Requires Brute-Force and Smart-Force Approaches.

Three factors to determine luminosity:

Stored current:

1.34 / 1.8 A (KEKB)

→ 4.1 / 9.4 A (SuperKEKB)

Beam-beam parameter:

0.057 (KEKB)

→ 0.19 (SuperKEKB)

Lorentz factor

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

Classical electron radius

Beam size ratio

Geometrical reduction factors due to crossing angle and hour-glass effect

Luminosity:

0.15×10^{35} $cm^{-2}s^{-1}$ (KEKB)

4×10^{35} $cm^{-2}s^{-1}$ (SuperKEKB)

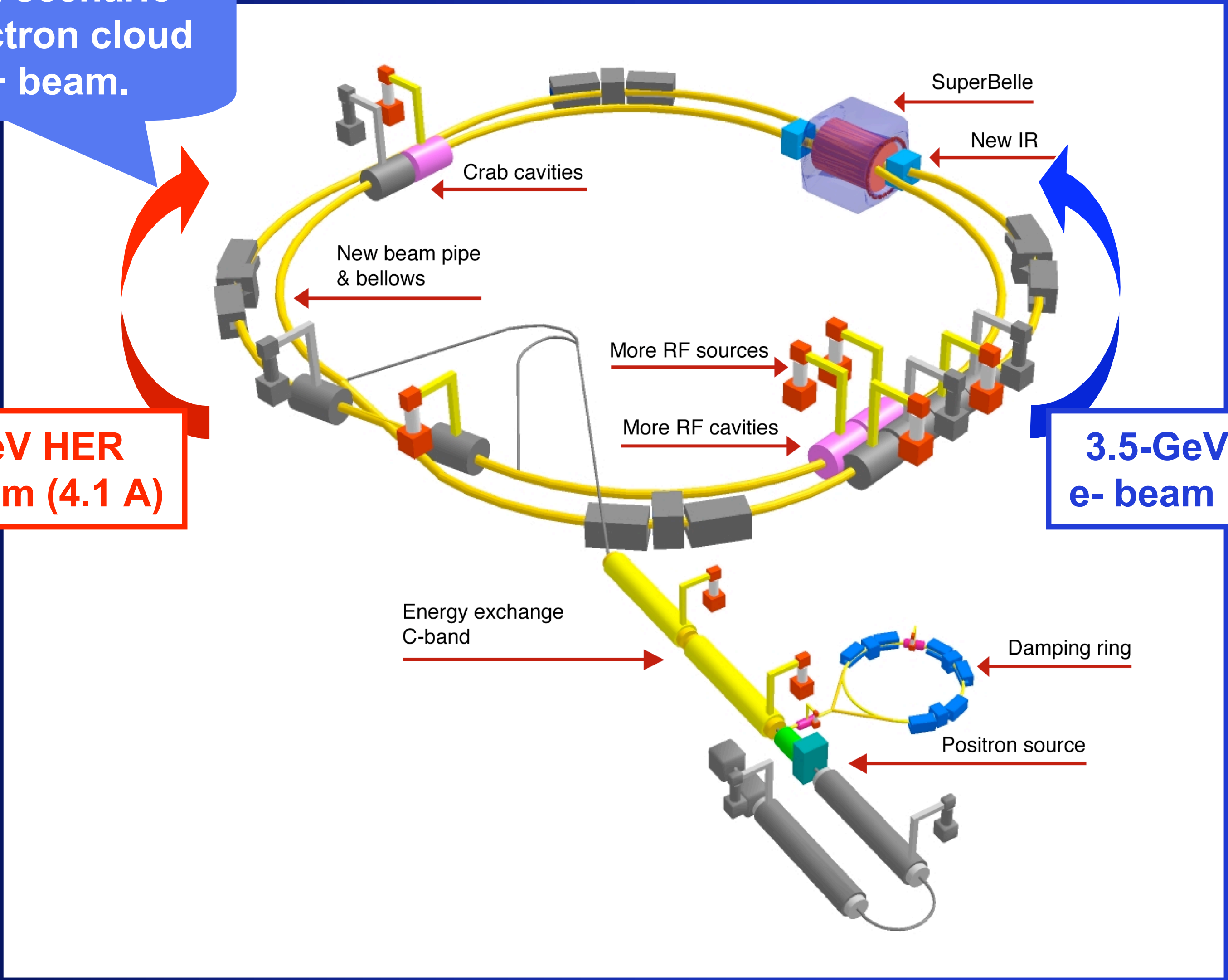
Vertical β at the IP:

5.2/6.5 mm (KEKB)

→ 3.0/3.0 mm (SuperKEKB)

SuperKEKB

Charge-switch scenario to ease the electron cloud effect on e+ beam.



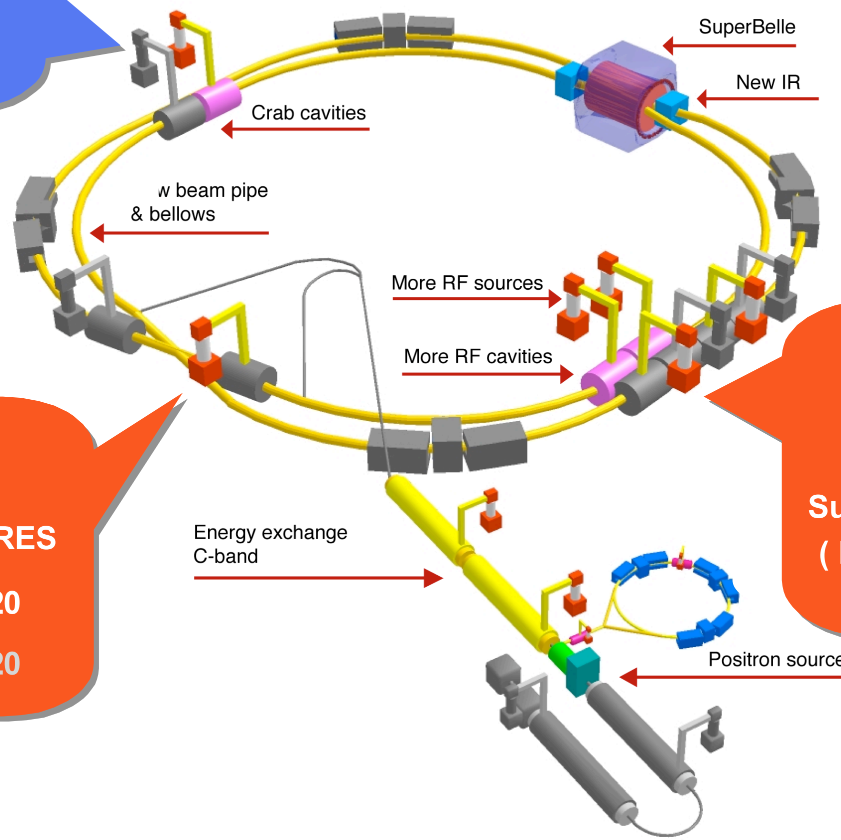
8-GeV HER
e+ beam (4.1 A)

3.5-GeV LER
e- beam (9.4 A)

SuperKEKB Requires More RF Sources and More RF Cavities

Nikko
SC RF section (HER)

	#Kly.*	#SCC
SuperKEKB	12	12
KEKB	8	8



Fuji
NC RF section (LER)

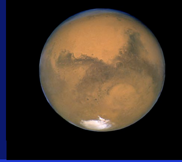
	#Kly.	#ARES
SuperKEKB	20	20
KEKB	10	20

Oho
NC RF section (HER&LER)

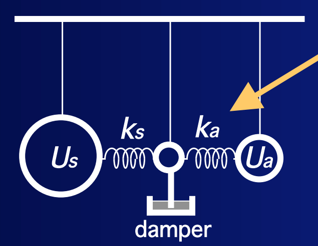
	#Kly.	#ARES
SuperKEKB (HER/LER	24 8 / 16	24 8 / 16)
KEKB	6	12

* 1MW CW Klystron (509 MHz)

Upgrading ARES Cavity



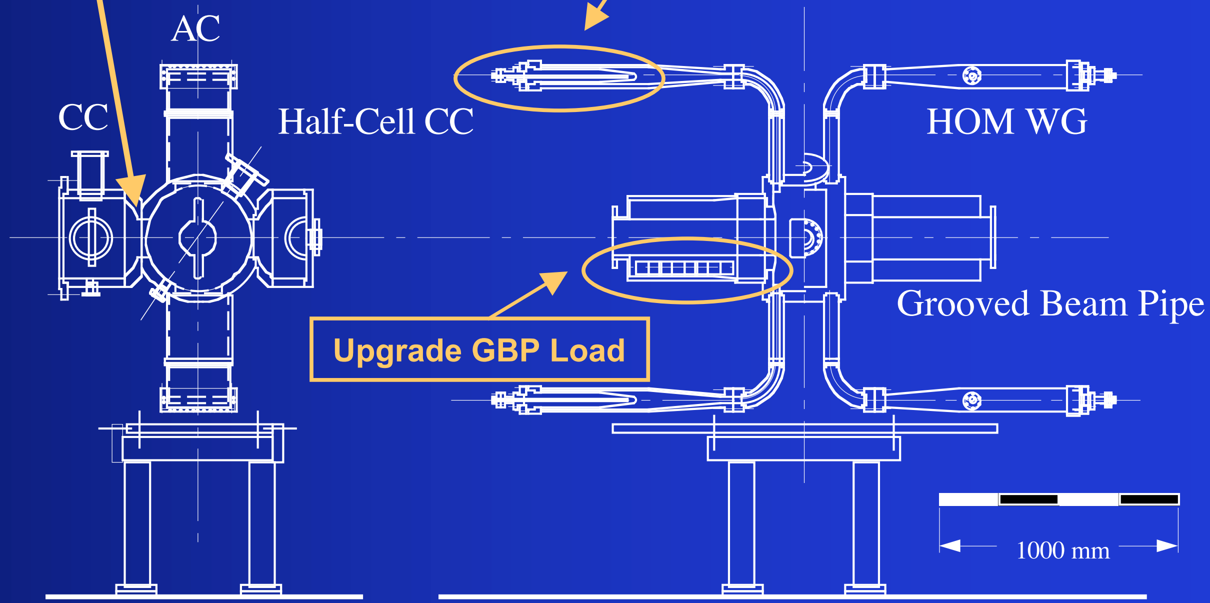
Increase k_a by enlarging the coupling aperture between A-cav and C-cav.



mode	S-cav	C-cav	A-cav
0	→	→	→
π/2	→	•	←
π	→	←	→

$$\frac{U_s}{U_a} = \frac{k_a^2}{k_s^2}$$ *for π/2 mode*

Upgrade HOM WG Load

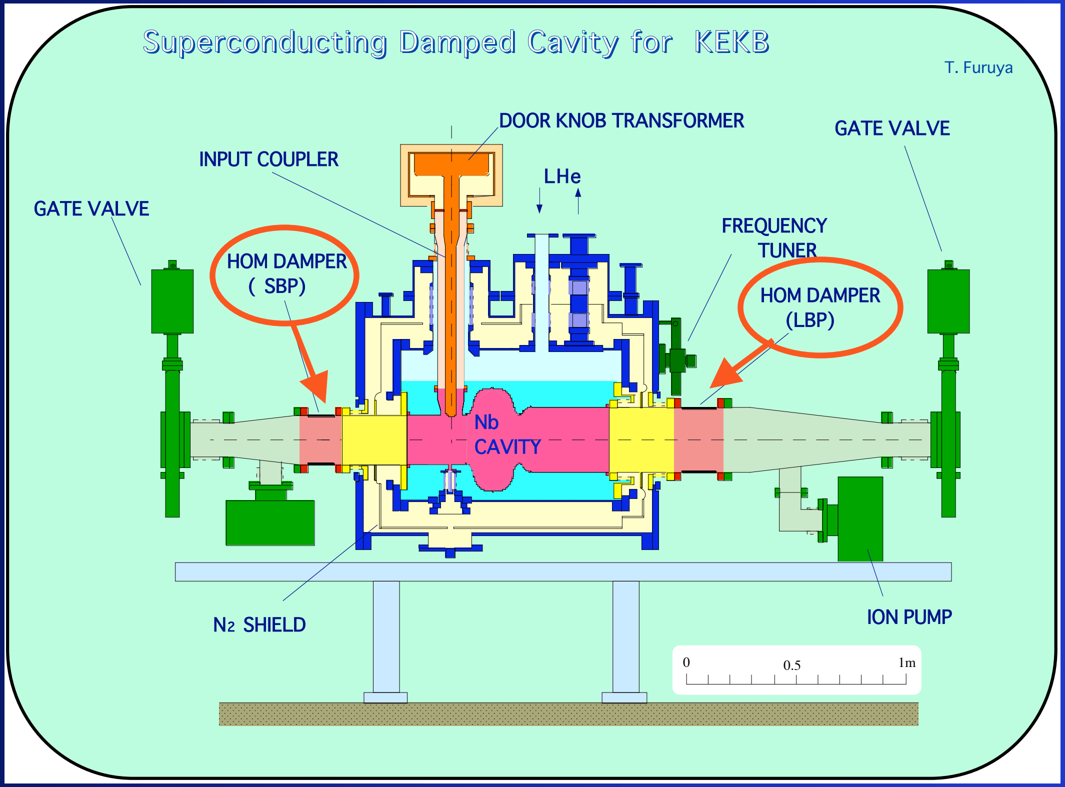


Upgrade GBP Load

- Fortunately, **ARES scheme** is flexible to upgrade: By increasing U_s/U_a from 9 to 15, the severest beam instability can be eased by one order of magnitude and manageable with an RF feedback system.

- The HOM absorbers (SiC) need to be upgraded: The HOM power per cavity is estimated about 90 kW for the design beam current 9.4 A for LER.

Upgrading Superconducting Cavity

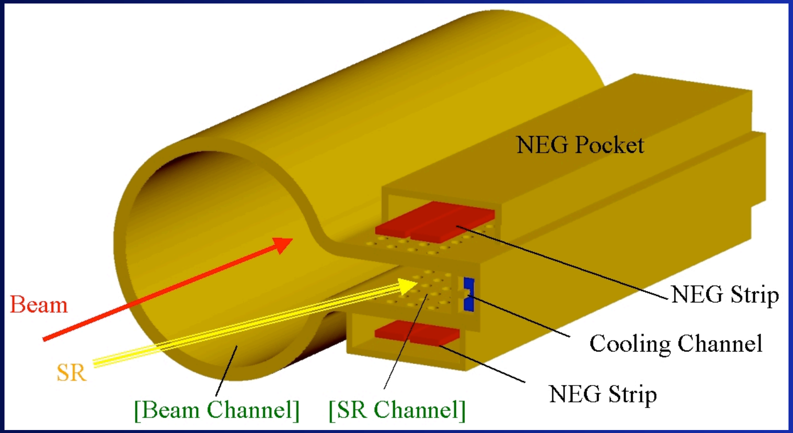


- **Cavity structure not changed.**

- **The HOM absorbers (ferrite) need to be upgraded: The HOM power per cavity is estimated about 50 kW for the design beam current 4.1 A for HER.**

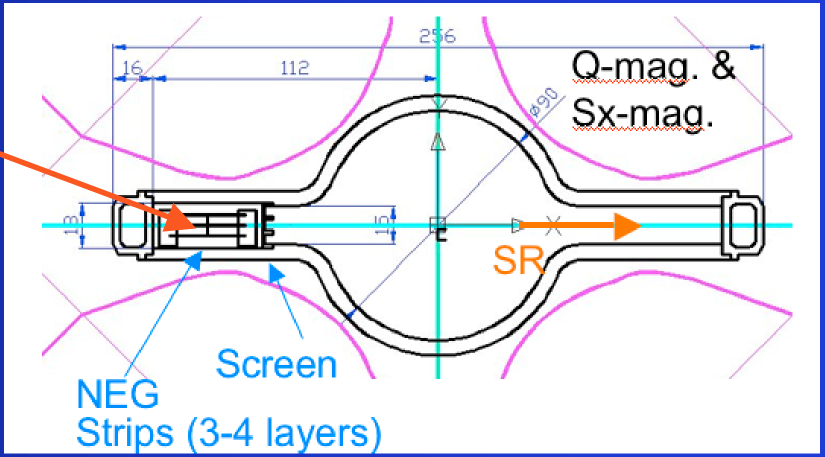
R&D of Vacuum Components for SuperKEKB

Beam duct with antechamber



- Smaller SR Power Density
- Lower Impedance
- Lower photoelectron production by TiN or NEG coating

New design with pumps in Q and SX magnets → uniform pumping



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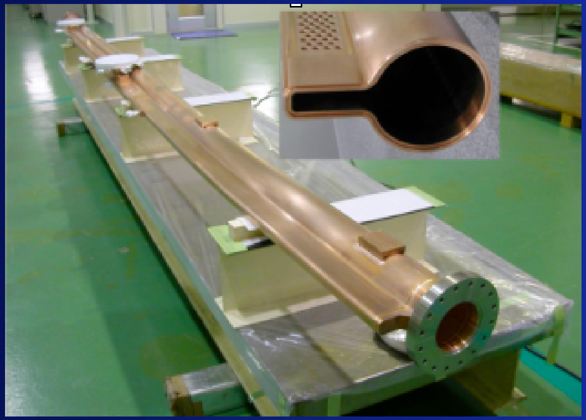
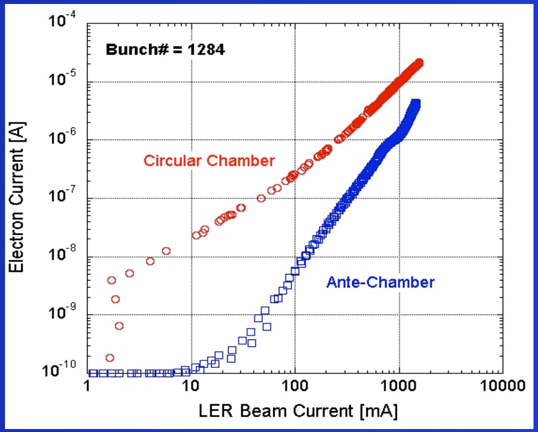
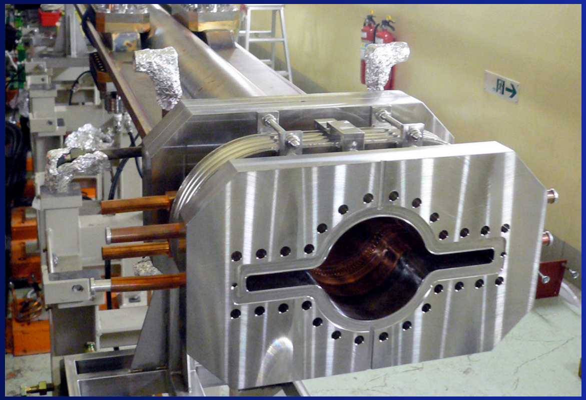
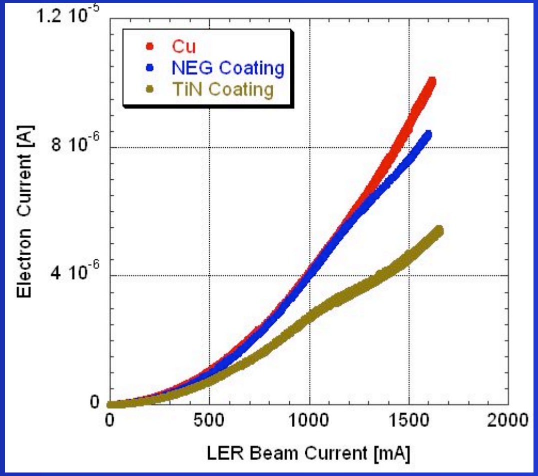
R&D of Vacuum Components for SuperKEKB

Beam duct with antechamber:
Prototype chambers have been tested in the KEKB LER.









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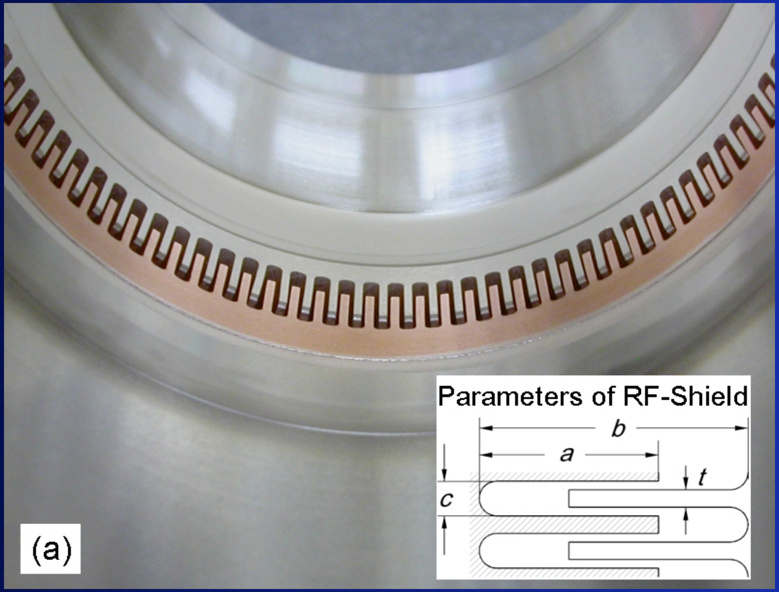
R&D of Vacuum Components for SuperKEKB

Bellows chamber with comb type RF-shield:
Some prototypes have been tested in KEKB and showing good performance.



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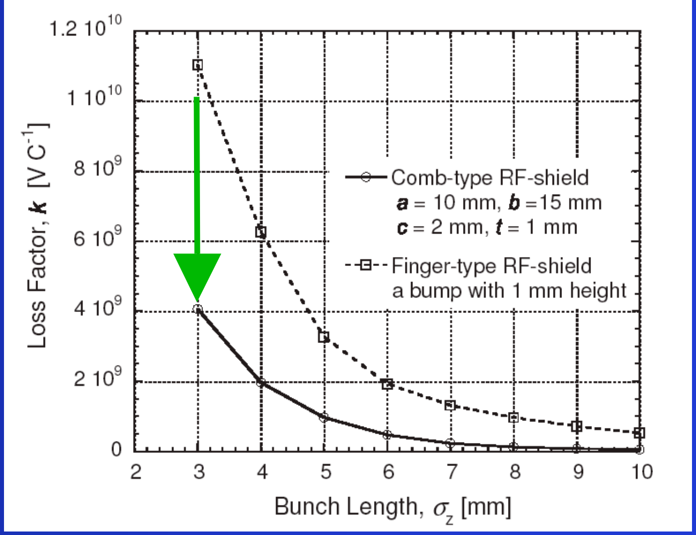
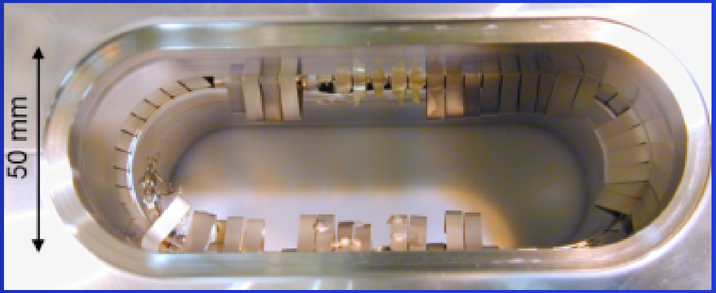
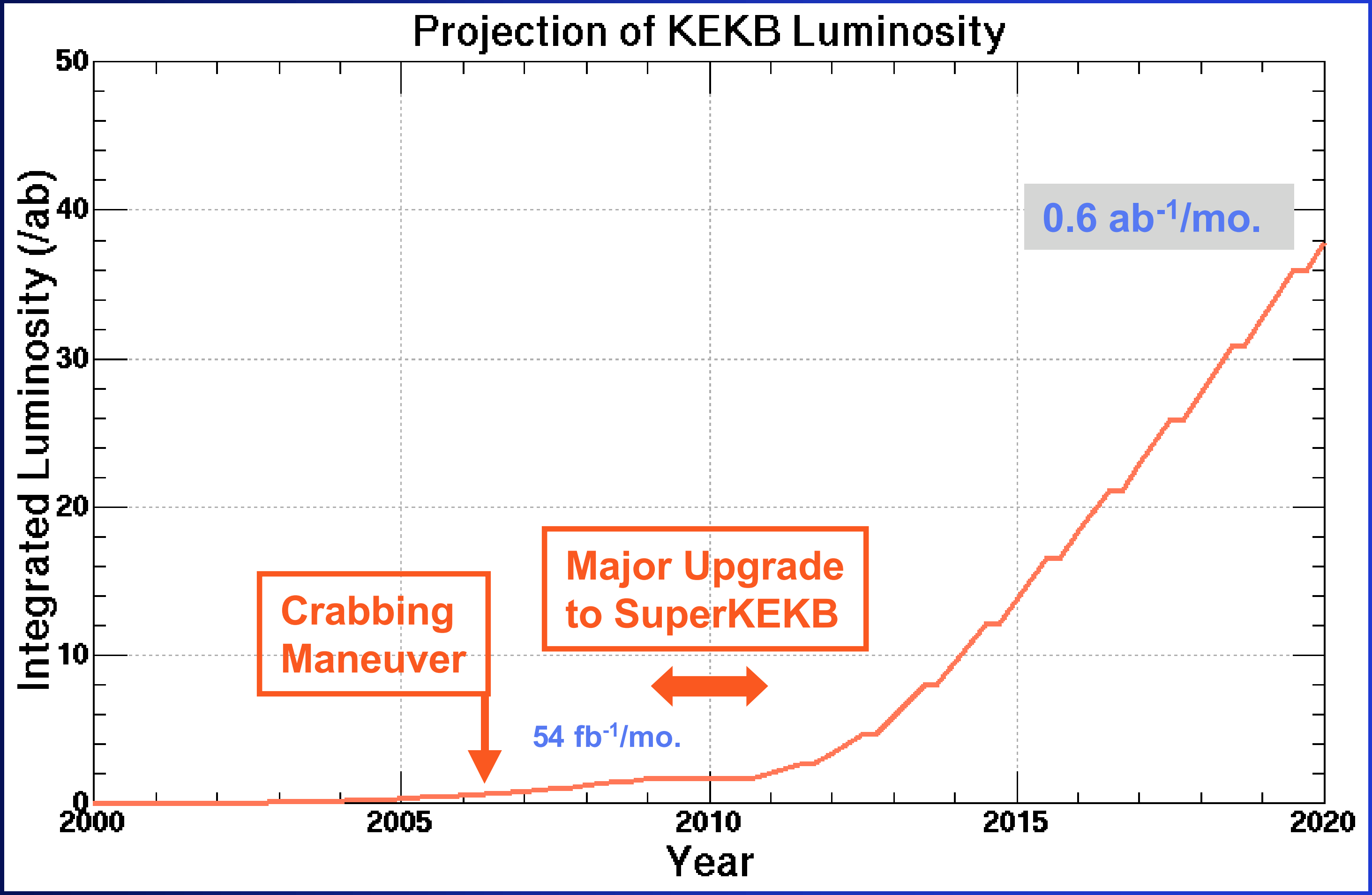


- High thermal strength
- Low impedance
- No sliding contact on the surface facing the beam



A bellows chamber damaged by the high-current beam.

A Scenario for Upgrading KEKB to SuperKEKB



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Summary

- KEKB has been the front runner on the luminosity frontier.
- Crabbing maneuver is going to be introduced in early 2006.
- 1 ab^{-1} will be reached around 2007.
- A technically feasible design of SuperKEKB for $4x10^{35}$ cm^{-2} s-1 has been done.

Followed by Backup Slides

SuperKEKB Machine Parameters

Parameters		LER / HER	Unit
Beam energy	E	3.5 / 8.0	GeV
Beam current	I	9.4 / 4.1	A
Particles/bunch	N	1.18×10^{11} / 5.13×10^{10}	
Number of bunches	n_b	5018	
Circumference	C	3016.26	m
Bunch spacing	s_b	0.6	m
Horizontal β at IP	β_x	0.2	m
Vertical β at IP	β_y	0.003	m
Bunch length	σ_z	0.003	m
Radiation loss	U_0	1.23 / 3.48	MeV/turn
Synchrotron tune	ν_s	0.031 / 0.019	
Horizontal betatron tune	ν_x	45.506 / 44.515	
Vertical betatron tune	ν_y	43.545 / 41.580	

Crab cavities		No		Yes		
Horizontal emittance	ε_x	30		24		nm
Coupling parameter	κ	6		1		%
Crossing angle	θ_x	30		0 (crab)		mrad
Luminosity reduction*	R_L	0.76		0.86		
ξ_x reduction*	R_{ξ_x}	0.73		0.99		
ξ_y reduction*	R_{ξ_y}	0.94		1.11		
Horizontal beam-beam*	ξ_x	0.079		0.137		
Vertical beam-beam*	ξ_y	0.051		0.218		
Beam-beam simulation		S-S	W-S	S-S	W-S	
Vertical beam-beam (simulation)	ξ_y	0.051		0.14	0.28	
Luminosity	L	1		2.5	5	$\times 10^{35}$ cm^{-2}s^{-1}

* nominal value

S-S : Strong-Strong simulation

W-S : Weak-Strong simulation

Table 1.1: Machine parameters of SuperKEKB.

from LoI for SuperKEKB

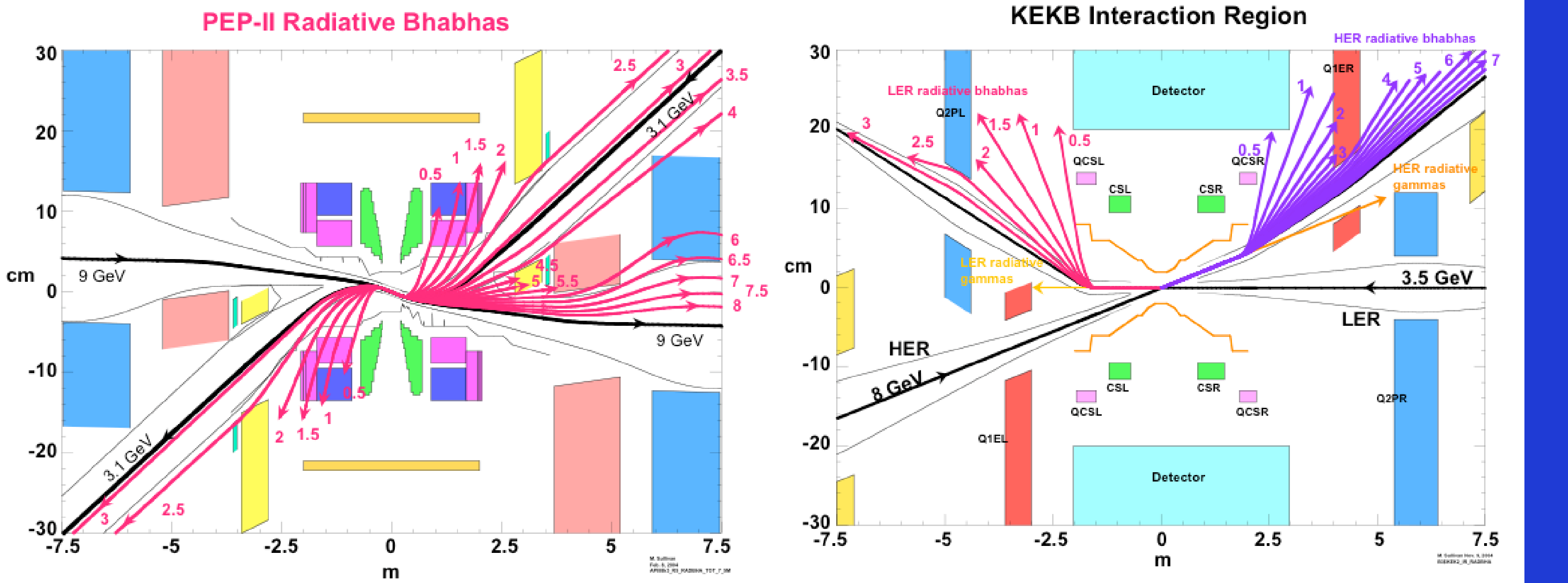
Machine Parameters

Table 1: Machine parameters of Super PEP-II at SLAC and SuperKEKB at KEKB.

	PEP-II		Super PEP-II		KEKB		SuperKEKB		
	LER	**HER**	**LER**	**HER**	**LER**	**HER**	**LER**	**HER**	
Energy	3.1	9.0	3.5	8.0	3.5	8.0	3.5	8.0	GeV
Particle	e^+	e^-	e^-	e^+	e^+	e^-	e^-	e^+	
Circumference	2200		2200		3016		3016		m
Current	2.45	1.55	15.5	6.8	1.69	1.24	9.4	4.1	A
Bunches	1588		6900		1293		5000		
Curr./bunch	1.54	0.98	2.25	0.99	1.27	0.98	1.88	0.82	mA
Spacing	1.26		0.31		1.77 or 2.36		0.59		m
Cross. Angle	0		30		22		30		mrad
Emittance ε_x	51	27	28	28	19	24	24	24	nm
β_x^*	30	50	15	15	59	56	20	20	cm
β_y^*	1.1	1.03	0.15	0.15	0.65	0.62	0.30	0.30	cm
Hor. Size @IP			65	65	103	103	69	69	μm
Ver. Size @IP			.6	.6	2.2	2.2	.73	.73	μm
Bunch Length	12.3	11.4	1.75	1.75	4.7	4.8	3.0	3.0	mm
RF Voltage		16.8	43	33	8	15	15	20	MV
RF Freq.	476		952		509		509		MHz
ξ_x	0.112	0.038	0.105	0.105	0.116	0.076	0.152	0.152	
$\xi_{x,\text{dynamical effects}}$	0.038	0.039					0.041	0.041	
ξ_y	0.064	0.043	0.107	0.107	0.092	0.056	0.215	0.215	
$\xi_{y,\text{dynamical effects}}$	0.054	0.037					0.187	0.187	
Luminosity	0.921		70		1.533		40		$10^{34}/\text{cm}^2/\text{s}$

Ref. H. Koiso, "Super B-Factories", PAC05

Beam-beam collision scheme:
Head-on, or with a finite crossing angle



Comparison of luminosity-dependent background due to radiative Bhabha events. Without crossing angle, this effect is significant.

M. Sullivan

RF Parameters for SuperKEKB

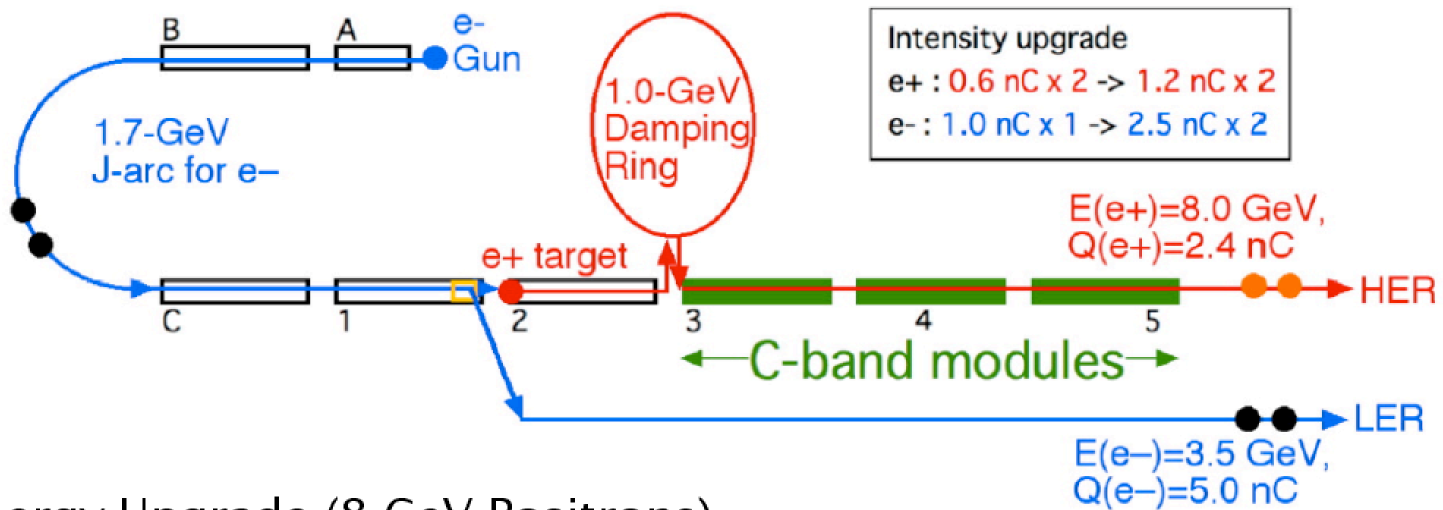
Parameters		LER	HER	Unit
Beam current	I_b	9.4	4.1	A
Energy loss/turn	U_0	1.2	3.5	MeV
Loss factor	k_{total}	40	50	V/pc
Bunch length	σ_z	3	3	mm
Radiation loss power	$P_{b,rad}$	11.3	14.3	MW
Parasitic loss power	$P_{b,para}$	7.1	1.7	MW
Total beam power	$P_{b,total}$	18.4	16.0	MW
Total RF voltage	$V_{c,\ total}$	14.0	23.0	MV
RF frequency	f_{RF}	508.887		MHz
Revolution frequency	f_{rev}	99.4		kHz
Cavity type		ARES	ARES/SCC	
# of cavities		28	16/12	
Voltage/cavity	V_c	0.5	0.5/1.3	MV
Beam power/cavity	P_b	650	650/460	kW
Wall loss/cavity	P_c	233	150/-	kW
Detuning frequency	Δf_a	45	31/74	kHz
# of klystrons		28	16/12	
Klystron power	P_{kly}	930	850/480	kW
Total AC power		40	23/10	MW

Guideline:

- Adopt the same RF frequency as KEKB.
- Make the most of the existing RF system.

K. Akai

Injector Linac Upgrade for SuperKEKB



Energy Upgrade (8 GeV Positrons)

Replace S-band (2856 MHz) RF system with C-band (5712 MHz) system to double field gradient in downstream section of linac.

(The present max. energy gain is 4.8 GeV)

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Injector Linac Upgrade for SuperKEKB

C-Band Linac for SuperKEKB

	S-band	C-band		
Parameters	KEKB	1-st prototype	2m-structure	Unit
total length	2.072	1.082	2.0	m
number of regular cells	54	54	108	
regular cell length (d)	35.0	17.5	17.5	mm
disk thickness (t)	5.0	2.5	2.5	mm
disk iris diameter (2a)	24.95 - 20.90	12.48 - 10.45	14.03 - 10.54	mm
cavity diameter (2b)	83.0 - 82.0	41.5 - 41.0	42.0 - 41.0	mm
group velocity (v_g/c)	1.4	1.9 - 1.0	2.8 - 1.0	%
shunt impedance	57	75 - 85	67 - 85	MΩ/m
Q factor	13700	9690	9700	
RF power in cells	30 - 15	34 - 15	50 - 15	
Field gradient	21	41.2 - 39.0	42.5 - 38.1	
Filling time	462	234	376	
Attenuation constant	0.302	0.434	0.696	

Table 11.3: Accelerating section characteristics

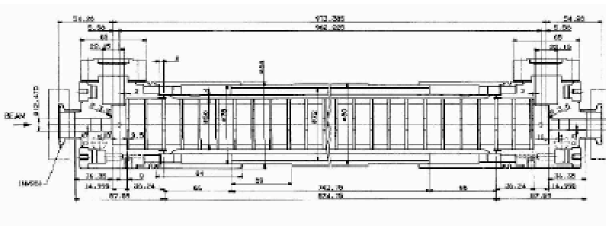
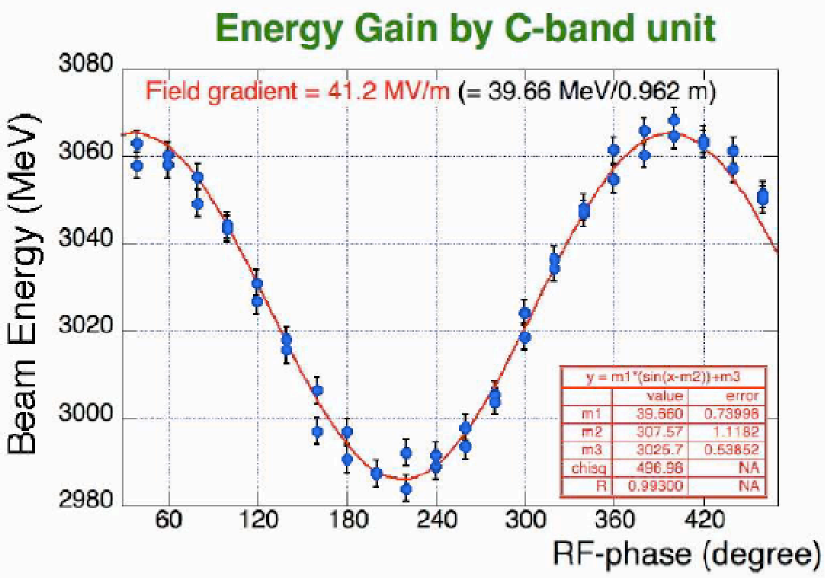


Figure 11.7: C-band 1m-long accelerating section (1-st prototy

Prototype C-band structure installed and tested at linac using actual beam (2003). Measured field gradient of 41 MV at 43 MW agrees with expectation.



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